Environmental Tritium Surveillance for Project Rulison

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Introduction

Project Rulison was the second nuclear experiment conducted jointly by the U. S. Government and private industry to investigate the feasibility of using nuclear explosives to stimulate production of natural gas from a low-permeability gas-bearing formation by producing a zone of fractured rock and a "chimney" of rock rubble around and above the detonation point. The void spaces thus produced provide a reservoir into which the natural gas can flow. A standard gas well is then drilled to the chimney, allowing recovery of the gas. This technique was shown to be successful in the first such experiment, Project Gasbuggy, conducted by the U. S. Government and El Paso Natural Gas Company near Farmington, New Mexico, in December 1967.[1] Project Rulison was conducted by the U. S. Atomic Energy Commission, Department of Interior, and Austral Oil Company near Grand Valley, Colorado. The nuclear device was detonated at a depth of 2570 meters below the ground surface in September 1969, and chimney re-entry and production testing of the test well extended from April 1970 through April 1971.

In accordance with a Memorandum of Understanding between the U. S. Public Health Service and U. S. Atomic Energy Commission, the Western Environmental Research Laboratory (formerly the Southwestern Radiological Health Laboratory of the Public Health Service)* conducted an off-site radiological surveillance program for the detonation, chimney re-entry, and production testing phases of the project. The detonation phase was completed with no release of radioactivity to the environment.[2,3] Re-entry operations to drill a well into the area of rubble and fractured rock near the detonation point began in April 1970. By

*Re-named the Western Environmental Research Laboratory on May 21, 1971 following its transfer from the Public Health service to the Environmental Protection Agency on December 2, 1970.

the time the area of broken rock was reached in July, most of the gaseous radioactivity originally produced by the detonation had decayed to stable nuclides. Essentially all of the non-gaseous radioactivity was expected to have been trapped in the solidified rock which melted during detonation, or on the chimney debris. Consequently, tritium and krypton-85 were the two remaining radionuclides of primary interest expected to be released to the environment as part of the natural gas that was to be burned, or "flared", at the surface during production flow tests on the test well. It was ~~predicted~~ assumed that after burning, any tritium present in the plume would be in the form of water vapor.

The off-site surveillance program was ~~thereby~~ therefore designed to monitor the environment for these radionuclides in particular. The program was also designed to monitor for carbon-14 and other radioactive products that might be released from the test well. Because of the relative ease of collecting atmospheric moisture for tritium analysis and the ~~approximately equal~~ somewhat greater public health significance expected for the released tritium ~~and krypton-85, tritium~~ it was chosen as the radionuclide for routine air surveillance. Net krypton-85 concentrations could be estimated from net tritium concentrations and the measured ratio of the two gases at the well-head. In addition, tritium would be the only radionuclide expected in other environmental samples. This paper reports the procedures and results of the off-site tritium monitoring program conducted during the re-entry and production testing phases by the Western Environmental Research Laboratory.

Background

The Project Rulison test well is located in a mountain valley approximately 64 kilometers northeast of Grand Junction, Colorado. The nearest community (Grand Valley population 300) is ten kilometers northwest of the site along the Colorado River. Figure 1 shows a map of the area. A 27.4 meter flare stack was erected about one hundred meters from the test well to burn the natural gas released during re-entry and production testing operations. The well-head is at an elevation of 2,480 meters above mean sea level in the upper end of Battlement Creek valley. Battlement Creek is one of several streams draining the slopes

of Battlement Mesa, a 3,290 meter flat-topped mountain. Battlement Creek has no flowing tributaries and originates from several ponds and reservoirs on top of Battlement Mesa, three to five kilometers southeast of the project site. The stream then flows within one hundred meters of the well-head, and continues northwest where it empties into the Colorado River at an elevation of 1,570 meters near the town of Grand Valley. About five kilometers downstream from the well-head near the Old Control Point Pad (used as an operations center for the detonation phase), the creek leaves the valley and crosses an alluvial fan area known as Morrisania Mesa.

Several ranches are scattered across Morrisania Mesa, many of which use Battlement Creek for irrigation and filling domestic water supply cisterns. The Clem Ranch, located near the mouth of Battlement Creek valley, is the nearest ranch to the test-well, and served as one of the primary surveillance stations in the area. Battlement Creek valley and Battlement Mesa mountain are uninhabited except for occasional hunters, fishermen, and ranchers tending stock. The Colorado River and its tributaries drain the north side of Battlement Mesa, while Plateau Creek and its tributaries drain the southern side, eventually emptying into the Colorado River about 35 kilometers downstream from Grand Valley. Various ranches and the communities of Grand Valley, Rifle, Silt, Collbran, Plateau City, and Mesa are located along these two waterways.

Table 1 - No change required on this page.

At the higher altitudes, the predominant wind direction across the Battlement Mesa area is toward the northeast. Occasional winds blow to the east or southeast, and other directions are relatively rare.(4) ~~These are the primary patterns for winds at the high altitudes.~~ Wind directions near the surface are influenced by the terrain and other factors, such as temperature inversions and nocturnal cooling. The predominant wind conditions in the vicinity of the test-well were of particular importance in terms of where the plume from the gas-flaring stack would be carried. The predominant day-time condition involved "up-slope" winds in the Battlement Creek valley, allowing the plume to rise and be carried over the 2,700 to 3,000 meter ridges immediately east and southeast of the test well. From there, the plume remained primarily under the influence of winds at those levels, although vertical mixing to lower altitudes occurred under some conditions. Plume travel to the nearest populated location under these conditions was usually 16 kilometers or more. Nocturnal flow under cloudy sky conditions usually remained "up-slope" under the influence of prevailing winds. With clear

sky conditions, a nocturnal down-slope or "drainage" wind in the Battlement Creek valley was common. The nighttime down-slope drainage wind was the normal occurrence. Under these conditions, a portion of the plume would be carried down the valley to the Morrisania Mesa area, while another portion would rise through the drainage wind layer to higher altitudes and be carried to the east. The relative amounts of plume material carried down-slope or up-slope under these conditions depended upon several factors, including the gas flow-rate, the depth and intensity of any temperature inversion, "drainage" wind intensity, and higher altitude wind direction and speed.

Drilling operations began on April 28, 1970 to "re-enter" the area of broken rock and establish a well so gas production tests could be conducted. The initial phase of this operation involved re-drilling an exploratory well located about one hundred meters from the nuclear device emplacement well, ~~used to emplace the nuclear device~~. After re-drilling to a depth of 1,980 meters, the test well was drilled at an angle calculated to intercept the rubble chimney slightly above the detonation point. Special drilling equipment and techniques were used to assure no gas was released from the well during drilling operations.

Once the area of broken rock was reached, the well was connected to various water and drilling mud separator systems on the surface. The material thus collected from the gas was stored in tanks ~~before~~ to await disposal ~~by the on-site radiation safety contractor or re-injection into the gas stream~~. The gas stream was monitored for radioactivity and other constituents by several sampling and monitoring systems before routing to the flare stack where it was burned in the atmosphere. As water accumulated in the tanks from the separator circuits, it was periodically injected into the gas stream to be vaporized in the flare.

The test well was completed ~~established~~ on July 28, 1970, and the first gas release occurred on August 1. Several short "calibration flaring" runs were scheduled thereafter to determine plume trajectories, dispersion parameters, and off-site radioactivity concentrations for several gas flow rates before full-scale production testing began. Operational problems were encountered when the gas lines became plugged with mud and rock debris from the well. Although the calibration tests were consequently cut short by this and other difficulties, sufficient information was gathered to indicate production testing could proceed.

Following remedial measures to re-open the well, production test flaring began in the fall of 1970. The various flaring operations conducted through the end of production testing in April 1971 are summarized in Table 1.

Table 1. Summary of Project Rulison Flaring Operations

Flaring Period	Start		End		Volume Gas Flared MMSCF
	Date	Flow Rate MMCFD*	Date	Flow Rate MMCFD	
Preliminary Flow Tests**	8/1/70	0.8-17.0	8/22/70	-	1
Calibration Tests***	10/4/70	2.0-15.0	10/7/70	-	12
High-Rate	10/27/70	17.0	11/3/70	11.4	109
Intermediate Rate	12/1/70	5	12/20/70	5	100
Long-Term	2/2/71	11.5	4/23/71	0.9	233

* MMCFD = Million Cubic Feet Per Day; MMSCF = Million Standard Cubic Feet.
** Nine short runs up to 8 hours duration.
*** Three short runs up to 14 hours duration.

Operational Procedures

The off-site environmental tritium monitoring program consisted of three basic efforts. These were (1) aerial plume tracking and sampling using a WERL fixed wing aircraft, (2) special intensive atmoshperic moisture sampling surveys during calibration flaring operations and selected periods of the long term flaring operations, and (3) regular sampling of air, water, milk, natural vegetation, soil, crops, animal tissue, and urine throughout the re-entry and production testing period. All samples were returned to the WERL in Las Vegas for analysis, with the exception of some stream and atmospheric moisture samples analyzed at a temporary field laboratory in Grand Junction, Colorado, during initial calibration flaring runs. Routine samples were shipped to Las Vegas daily by commercial air transportation. Aerial and other special samples were returned to Las Vegas immediately after collection on Laboratory aircraft. Analytical data were transmitted to Colorado for field operation guidance and to Project Rulison Open Files maintained in Las Vegas, Denver, and Bartlesville, Oklahoma, by the Atomic Energy Commission for data dissemination to the public.

Aerial plume tracking and sampling were performed with a twin-engined Turbo-Beech aircraft. Since radioactivity levels in the plume from the gas flaring stack were so low that gamma and beta detectors could not be used, plume tracking was accomplished with a condensation nuclei monitoring instrument, manufactured by Environment/One Corporation of Schenectady, New York. This typewriter-sized instrument, which measured the airborne concentration of condensation-nuclei resulting from burning of the natural gas, was mounted in the aircraft cabin, immediately behind an air baffle at the discharge end of an air sampling probe mounted in the nose of the aircraft. The instrument output was fed to a strip chart recorder in the co-pilot's instrument panel, providing the crew chief with continuous information on plume trajectory, size, and dispersion. This information was ~~used to determine sample collection locations, and~~ was radioed to a ground control center so ground monitoring personnel could be positioned to collect samples in the plume ground track.

Atmospheric moisture samples were collected from the aircraft sampling probes with a cryogenic sampling system and a "grab" sampler. The cryogenic system collected an integrated sample of atmospheric moisture, carbon dioxide, and noble gases over a 30-minute sampling period while the aircraft circled or spiraled in the plume. The cryogenic sampler consists of a series of traps submerged in liquid nitrogen. Water vapor is frozen out in the initial trap.

"Grab" samples were obtained by gathering air from the sampling probe in a one-cubic meter plastic bag over a 30-second period, and then pumping the air through a cannister containing 1000 grams of Linde type 13x molecular sieve for water vapor and CO_2 collection, and then into a compressed air bottle.

The bottled air and cryogenic sampler were returned to the Laboratory for noble gas analysis to obtain further information on radionuclide concentrations in the plume. Water and CO_2 recovered from the molecular sieve and cryogenic sampler were used to determine tritium and carbon-14 concentrations.

Portable battery-powered air samplers were used to collect atmospheric moisture samples at ground level during the special surveys. Based on aerial tracking information, monitoring personnel drove to ground stations along roads

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or were airlifted by helicopter to otherwise inaccessible areas in the downwind trajectories. The monitors were located at predesignated sampling stations and carried portable two-way radios to receive instructions concerning sampling times and position changes. The portable sampler consisted of a Sears, Roebuck and Co. automobile vacuum cleaner powered by a 12-volt automobile battery. Air flow was measured by a Rockwell dry gas meter. Air was first passed through a 10.2 cm diameter glass fiber filter to remove particulates, and then passed through a 300 gram molecular sieve cannister to remove the moisture. Sampling time was controlled to collect between 10 and 20 ml of water, based on field calculations of absolute humidity. Humidity measurements were made with sling psychrometers. Airborne concentrations of tritium were based on the sample volume, tritium concentration in water vapor, and calculated absolute humidity until winter weather reduced the reliability of sling psychrometer measurements. After that, total water collected was used to determine absolute humidity. Battery powered compressors and a truck mounted cryogenic sampler were also used to collect air samples for tritium and noble gas analysis. Carbon-14 analysis was performed on the CO_2 from representative molecular sieve and cryogenic samplers.

Continuous collection of atmospheric moisture during flaring periods was accomplished at seven fixed monitoring stations at populated locations in the vicinity of the test well (shown in Figure 1). Metal storage sheds were set up to house the samplers. Air was drawn through a particulate filter ~~exposed to the~~ outside of the shed, and then through a cannister containing 700 grams of molecular sieve for water collection. The sampler operated for 48-hour periods at an average flow rate of 3 lpm, controlled by a limiting orifice. The total volume of air sampled each period was calculated from the flow rate and operating time. Absolute humidity was determined from the total volume of water collected.

During the initial flaring operations, a dehumidifier unit developed by the Eastern Environmental Radiation Laboratory (formerly the Southeastern Radiological Health Laboratory of the Public Health Service) was also operated at each station to collect atmospheric moisture samples which were then counted for tritium with a special scintillation flow cell unit at the Grand Junction field laboratory. This provided a means of collecting a moisture

sample at any given time for a rapid assessment of atmospheric tritium concentrations. Daily water samples from Battlement Creek were also counted in this manner during initial flaring operations.

Temperature and humidity data at each station was recorded continuously by a hygrothermograph located in a standard meteorological instrument shelter located at least three meters from the sheds housing the various pieces of sampling equipment. Absolute humidity calculated from data provided by the recording hygrothermograph was used with counting data from the dehumidifier to determine atmospheric tritium concentrations if any positive samples were obtained.

Precipitation collectors were provided at each of the seven fixed sampling stations, and portable precipitation collectors were deployed by field personnel at other locations as conditions dictated. Funnels with an open area of 530 cm^2 were placed on the sampling shed roof-tops for precipitation collection. Precipitation was routed from the funnel to a graduated cylinder inside the shed. Portable samplers consisted of plastic sheets held 0.3 meter above the ground on a one-by-one-meter frame. Water collected in this manner was drained into a container for shipment to the laboratory. Several snow samples were collected with this device, and many other "grab" snow samples were collected, during the winter flaring operations.

Continuous water samples were collected from two stations on Battlement Creek with battery-powered Brailsford and Co. automatic samplers. One sampler was located about 100 meters downstream from the test-well, and the second about five kilometers downstream, near the mouth of Battlement Creek valley and just ~~prior to~~ upstream from the first withdrawal point for domestic water supplies. Daily 3.8 liter samples were collected in this manner until October 7, 1970, when the samplers had to be removed due to freezing weather. After that, a daily grab sample was collected at the lower station during flaring operations.

All other water sampling stations were sampled on a monthly schedule. The sampling stations included the following types of supplies.

10 streams	4 springs
4 reservoirs	15 municipal supplies
6 wells	

should be consistant in use of units. Page 9, line 19 refers to MDA in units of pCi/L.

Special atmospheric moisture samples collected with dehumidifiers and portions of the Battlement Creek samples collected during the early flaring operations were counted on a special scintillation system at the Grand Junction field laboratory. This system was developed at the WERL on the basis of work reported by Burt and Gibson.(5) A spiral flow cell filled with anthracene crystals was optically coupled to a photomultiplier with output to a scaler-timer. Voids volume in the cell was 0.8 ml. Due to the high background, approximately 0.5 mR/h, the minimum detectable concentration of tritium was 600 pCi/ml of water. Although this was far above the normally expected concentrations for atmospheric moisture or water from Battlement Creek, it provided a wide margin of safety as a rapid analysis tool for public protection. With normal absolute humidities of less than 5 ml water per cubic meter of air, a detection limit of less than 3,000 pCi/m^3 was provided, compared to the allowable exposure to a suitable sample of the population, averaged over a year, of 67,000 pCi/m^3. A satisfactory margin of safety was provided, also, for surface water with an allowable concentration of 1,000 pCi/ml averaged over a year.

Results of tritium analysis performed in Grand Junction were available the day the sample was collected. All data and work sheets were transmitted by Telecopier to Las Vegas on a daily basis for inclusion into the Project Rulison Open Files.

Results

Samples of atmospheric moisture, water, milk, precipitation, natural vegetation, soil, food crops, bovine feed, animal tissue, and urine were collected prior to any release of gas and analyzed to determine the background levels of tritium in each type of sample. The background sample results and the highest "above-background" results associated with flaring operations are shown in Table 3.

~~Table 3.~~ Environmental Levels for ^{3}H in the Project Rulison Area

Sample Type	Background Range (pCi/ml H_2O)	Highest Above-Background Result (pCi/ml H_2O)
Atmospheric Moisture	0.5 - 2.6	59
Water (stream)	<0.4* - 1.6	None
Water (well)	<0.4 - 0.95	None
Water (spring)	<0.4 - 1.4	None
Water (all)	<0.4 - 1.6	None
Milk	<0.4 - 2.1	None
Precipitation	<0.4 - 2.1	47
Natural Vegetation	<0.4 - 5.8	21
Soil (surface)	<0.4 - 1.4	6.7
Soil (15 cm depth)	<0.4 - 1.1	None
Soil (all)	<0.4 - 1.4	6.7
Food Crops	0.42 - 3.1	None
Bovine Feed	0.68 - 4.0	None
Animal Tissue	0.62 - 1.5	180
Urine	<0.4 - 1.1	None **

** ~~Several individuals~~ Urine from several individuals in the area indicated ^{3}H concentrations ranging to 9.5 pCi/ml, but these "above-background" ~~results~~ values were shown to result from wearing tritium-activated luminous dial watches, not Project Rulison activities. (7)

*Minimum detectable activity.

** The 3.8 ~~nCi/l~~ pCi/ml value is considered erroneous. A value of 1.7 ~~nCi/l~~ pCi/ml from the second highest sample is considered more representative for the upper range of background.

on what basis is it considered erroneous. It is not out of line with the maximum value for food crops (3.1) or bovine feed (4.0). I do not see any justification for throwing this value out.

All samples collected by the WERL were collected off-site (greater than 180 meters from the flare-stack) except for tissue from two porcupines which grazed directly under the flare-stack for several days. Tissue from these porcupines contained elevated levels of tritium as high as 180 ~~nCi/l~~ pCi/ml of water. The levels in the tissue water were still below the ~~Maximum Permissible Concentration~~ Concentration Guide (CG) for tritium in water for the general off-site population (1×10^3 ~~nCi/l~~ pCi/ml of water).(4) All other animal tissue and blood samples collected during the flaring operations contained background levels of tritium.

All samples of milk, water, food crops, and bovine feed, ~~and urine~~ collected during and after the flaring operations also contained background levels of tritium. Some samples of atmospheric moisture, precipitation, natural vegetation, and soil collected in the off-site area contained ~~levels~~ concentrations of tritium greater than background, ~~levels~~. These elevated ~~levels~~ concentrations were observed in generally isolated instances during flaring operations, and were not observed as continuing elevated levels of any duration, either during or after a flaring operation. Urine samples from several residents in the area indicated ^3H concentrations ranging to 9.5 pCi/ml, but these "above background" values were shown to result from wearing tritium-activated luminous watches, not Project Rulison activities (7)

The highest tritium ~~level~~ concentration in an atmospheric moisture sample collected during the flaring was 59 ~~nCi/l~~ pCi/ml of water, equivalent to 290 pCi/m^3 of air. This was less than one percent of the ~~MPC~~ CG for the general off-site population (6.7×10^4 pCi/m^3 of air). This sample was collected in an unpopulated location on top of Battlement Mesa during a calibration flaring period ~~1.3~~ 1.3 kilometers downwind from the flare stack.

Slightly elevated ~~levels~~ levels of tritium were also observed in populated areas around the flare stack. The highest level in an atmospheric moisture sample collected at a populated location was 11 ~~nCi/l~~ pCi/ml of water, or 21 pCi/m^3 of air. This is less than 0.1 percent of the off-site ~~MPC~~ CG. This sample was collected at the closest population location (about 5 kilometers) to the flare-stack. Slightly elevated levels of tritium were also detected in the DeBeque, Grand Valley, Rifle, and Collbran areas for short periods of time (see Figure 1).

The highest tritium ~~level~~ concentration in a precipitation sample collected during the flaring operation was 47 ~~nCi/l~~ pCi/ml of water. This was a snow sample collected

about 0.2 kilometers from the flare-stack during a wintertime flaring operation. This is less than five percent of the off-site ~~MPC~~ CG for tritium in water. The highest ~~level~~ concentration of tritium in a precipitation sample collected from a populated location was 2.5 ~~nCi/l~~ pCi/ml of water in a rain sample collected 7 kilometers northwest of the flare-stack. This ~~level~~ concentration of tritium is only slightly greater than background, and is less than one percent of the off-site ~~MPC.~~ CG

A vegetation sample collected from the top of Battlement Mesa immediately following a calibration flaring operation contained the highest tritium ~~level~~ concentration detected in vegetation. This was 21 ~~nCi/l~~ pCi/ml of water, or 7.6 nCi/kg wet weight. The highest tritium level detected in a vegetation sample collected at a populated location was 3.0 ~~nCi/l~~ pCi/ml of water, or 1.3 nCi/kg wet weight. This sample was collected near Silt, Colorado.

A surface soil sample collected 0.4 kilometers northwest of the test well contained the highest tritium level detected in soil of 6.7 ~~nCi/l~~ pCi/ml of water. The highest tritium ~~level~~ concentration detected in a soil sample collected at a populated location was 2.8 ~~nCi/l~~ pCi/ml of water at Collbran.

Discussion

Aerial tracking and sampling of the plume from the natural gas flaring stack indicated a variety of plume trajectories and dispersion patterns could occur within a 24-hour period. Plumes varied from non-dispersive types that rose to an altitude of 3000 meters or more and did not disperse to ground level when tracked for 30 kilometers, to "split" plumes where some material traveled at ground level in downslope drainage wind while the remainder of the plume rose through the associated temperature inversion layer to be dispersed to ground level later by vertical mixing. Based on the aerial tracking information, numerous environmental samples were collected during and following plume passage over populated and unpopulated downwind areas under varying meteorological conditions. The results indicated short-term elevated tritium concentrations occurred in some environmental media at widely scattered locations, and that the highest levels were only small fractions of applicable annual ~~MPC~~ CG recommendations. In addition, these elevated concentrations occurred for very short

periods of time (usually hours, in the case of atmospheric moisture) or represented no significant large scale source of population exposure (in the case of precipitation, natural vegetation, and soil).

Elevated tritium concentrations in atmospheric moisture were found to be the most likely source (and possibly only source) of population exposure from Project Rulison activities. Slightly elevated concentrations found in natural vegetation, soil, and precipitation were from a few isolated samples from scattered locations, and represented no wide-spread contamination that could provide a significant source of exposure to man. No concentrations above background were observed in water, milk, food crops, or animal tissue (domestic livestock or wildlife) that could be consumed by man. The only elevated tritium concentrations found in animal tissue occurred in two small herbivores (porcupine) that grazed extensively on a small patch of vegetation that remained green within a few meters of the flare stack during an extended wintertime flaring operation. This patch remained green as a result of heat generated by the flare, while the surrounding area was covered by snow and all other vegetation was dormant. The tritium in the forage eaten by these animals was probably primarily due to uptake from the "rain-out" of moisture which condensed from the plume in the immediate stack vicinity. Other wildlife samples (such as deer and elk) collected within several kilometers of the flaring stack gave no indication of elevated tritium levels.

Since this surveillance showed that atmospheric moisture was the only source of tritium exposure to man, the monitoring data from these samples were used to estimate a possible dose from the flaring operations. Estimates were prepared for each of the continuous monitoring stations operated at populated locations, including the one nearest the test well at the mouth of Battlement Creek valley. The net average concentrations ~~above background~~ for each sampling period were integrated over the respective sampling periods, summed for all periods, and then converted to dose using conversion parameters presented in ICRP-10.[8] These estimates showed the maximum dose to a resident in the Project Rulison area from exposure to tritium was less than 0.001 mrem. Urine samples collected from residents showed no measurable exposure from Project Rulison activities.

Release concentrations of tritium and krypton-85 were approximately equal. A similar relationship was found in air samples. On this basis the resulting dose from krypton-85 released from Project Rulison flaring would be approximately equal to that from tritium.

One of the more interesting observations encountered during the Project Rulison surveillance program involved elevated tritium levels in urine collected from area residents as a result of wearing wrist watches with tritium-activated luminous dials. This occurrence was first noticed in background samples collected from three residents prior to flaring gas from the test well. A subsequent study involving these residents and two volunteer Laboratory employees indicated their watches were losing tritium, and that when their watches were removed for several days, the tritium concentrations in their urine decreased. When the individuals resumed wearing the watches, urine tritium concentrations rose to their original level. Although no increase in urine tritium concentrations was detected as a result of Project Rulison flaring operations, concentrations ranging up to ten times background were measured in persons wearing tritiated wrist watches. The estimated average annual dose to wearers of the watches ranged from 0.2 to 1.8 mrem. The Laboratory is continuing its investigation of this question, and details of this wrist watch study are to be reported soon.[8]

Summary

A comprehensive environmental tritium surveillance program conducted by the Western Environmental Research Laboratory showed no significant increase in environmental tritium concentrations as a result of production testing operations for Project Rulison. Release of tritiated natural gas from a rubble chimney created by a nuclear explosion produced short-term tritium concentrations from one to two orders of magnitude above background levels in atmospheric moisture, precipitation, vegetation, and soil samples collected near the experimental well and gas flaring stack. Tissue samples from two herbivores (porcupine) that grazed extensively within a few meters of the flaring stack contained elevated tritium concentrations, while all other animal tissue samples showed only background concentrations. Water, food crops, milk, and urine samples also showed no increase in tritium concentrations as a result of Project activities. Dose estimates indicate the maximum postulated dose from tritium to a resident in the area was less than 0.001 mrem.

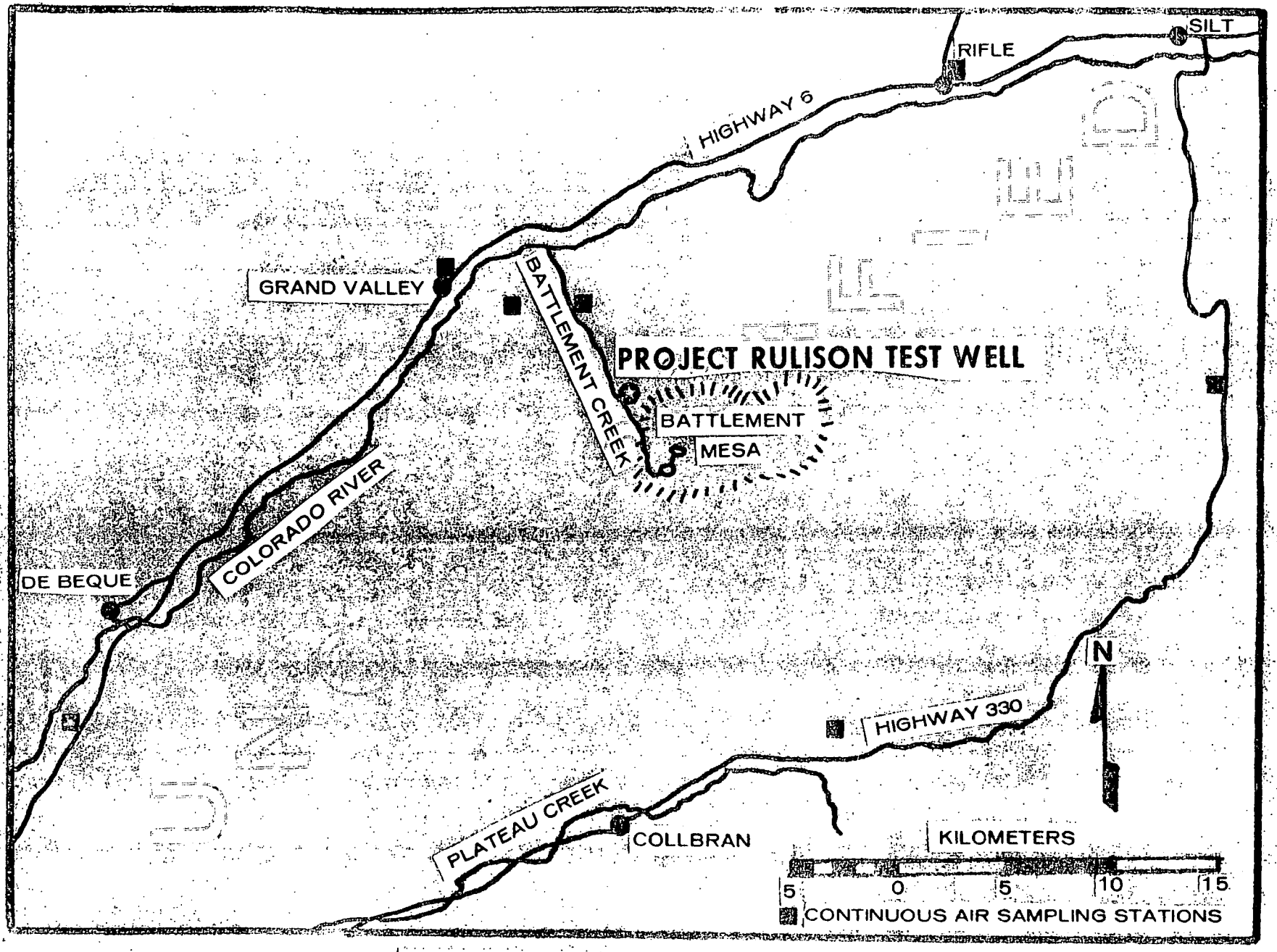

FIGURE 1. PROJECT RULISON AREA

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